

Unit 9 Notes, Part 2: The Nervous System

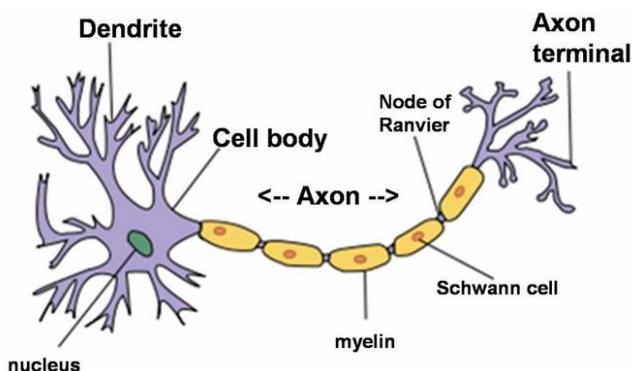
Ms. Ottolini, AP Biology

How do cells send signals?

1. By direct **physical / chemical contact** (ex: plant cell communication through plasmodesmata)
2. By using the **nervous system** to transmit signals quickly over short distances
3. By using the **endocrine system** to release hormones from glands into the bloodstream to travel long distances to multiple target cells / tissues / organs. This is a slow method of cell signaling but it can produce many effects in the body.

What is the basic unit of the nervous system?

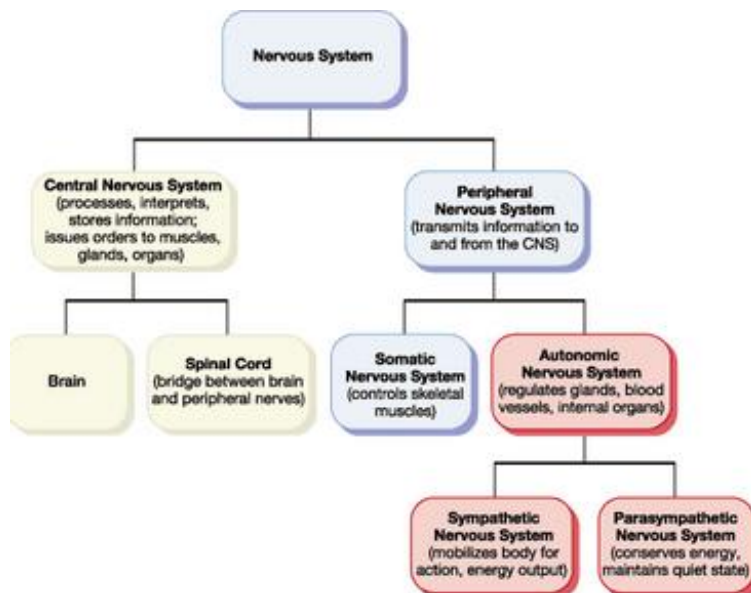
4. Nerve cells (aka **neurons**) are the basic unit of the nervous system.
5. Nerve cells contain
 - dendrites** that receive signals
 - a **cell body** that houses most of the organelles and the nucleus of the cell
 - a long **axon** that transmits the signal down the length of the cell
 - axon terminals** that release chemical signaling molecules (i.e. **neurotransmitters**) to travel to other nerve cells or muscle cells



6. Along the length of the axon are **Schwann cells** made of an insulating material called **myelin sheath**. The spaces between Schwann cells on the axon are called **Nodes of Ranvier**. The Schwann cells increase the speed of the nerve signal because the signal jumps from one Node of Ranvier to the next in a process called **saltatory conduction**.

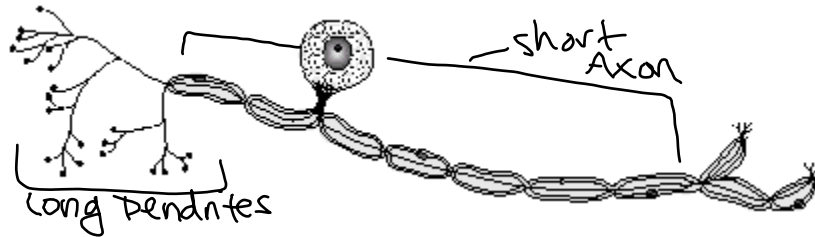
What are the major divisions of the nervous system?

7. The nervous system is made of two main divisions: the **Central Nervous System (CNS)** and **Peripheral Nervous System (PNS)**
8. The CNS consists of the brain and spinal cord. All neurons in this division of the nervous system are a type of neuron called an **interneuron**.
9. The PNS contains all nerve cells outside the brain and spinal cord. All neurons in this division of the nervous system are either **sensory neurons** or **motor neurons**.
10. The CNS and PNS are further broken down according to the diagram to the right.

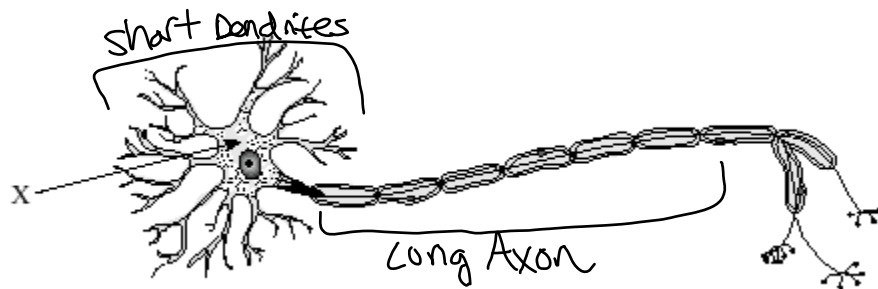


What are the types of neurons?

11. **Sensory neurons** send information from sensory receptor cells to the CNS. Sensory receptor cells receive information about touch, taste, sound, sight, smell, temperature, and pain. Sensory neurons typically have long dendrites to receive signals and short axons. The picture below shows a sensory neuron.



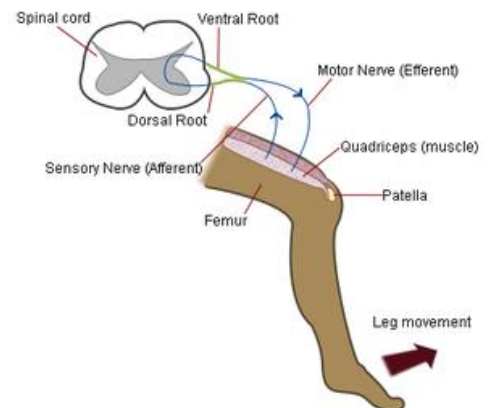
12. **Motor neurons** send information from the CNS to direct muscle movement. Motor neurons typically have short dendrites and long axons to transmit information to muscle cells. The picture below shows a motor neuron.



13. **Interneurons** in the brain and/or spinal cord integrate information from sensory neurons and transmit the information to motor neurons. Interneurons typically have short dendrites and short axons.

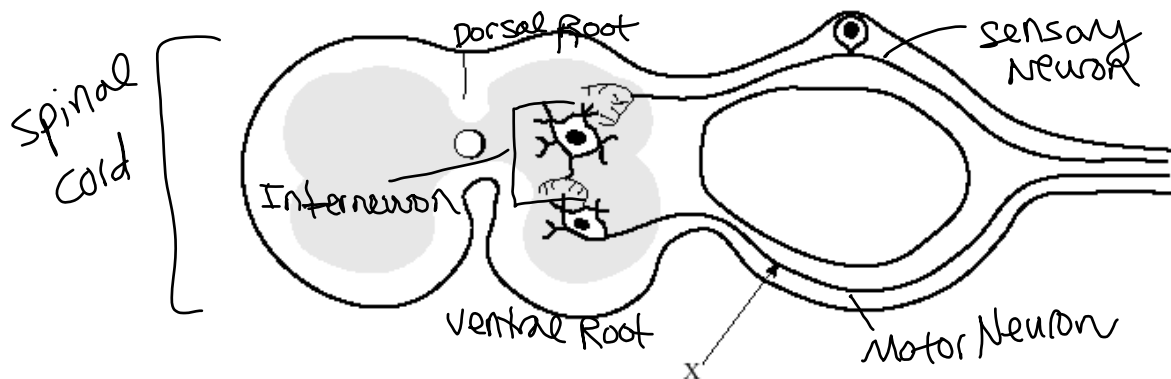
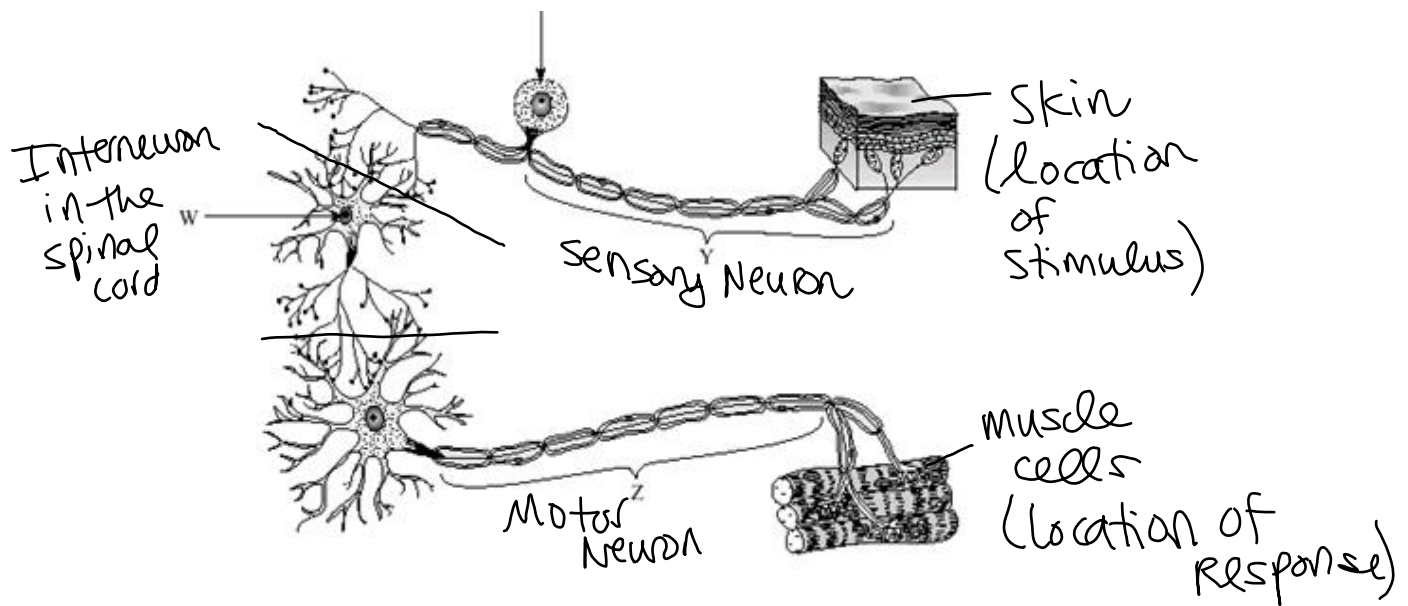
How do the different types of neurons work together to sense and respond to environmental stimuli?

14. Some sensory / motor neurons participate in a **reflex arc** that “bypasses” the brain. For example, the **knee jerk reflex** occurs when you get hit just below your knee cap. (*Note: Doctors typically check this reflex as part of a normal physical with a small mallet.*)
- First, the mallet hits your leg, triggering a sensory neuron.
 - The sensory neuron carries the signal to the **dorsal root** of the spinal cord (dorsal meaning facing the back side of your body).
 - The sensory neuron sends the signal to a motor neuron, which leaves the spinal cord through the **ventral root** (ventral meaning facing the front side of your body).



- The motor neuron sends the signal to your quadriceps muscle along the top of your thigh, which contracts / shortens and causes your foot to swing forward / up.
15. The reflex arc discussed above is **monosynaptic**, meaning there are no interneurons involved. Some reflex arcs are **polysynaptic**, meaning they do involve one or more interneurons in the spinal cord (but not the brain). Your teacher will help you label the polysynaptic reflex arcs on the next page.

Polysynaptic Reflex Arcs

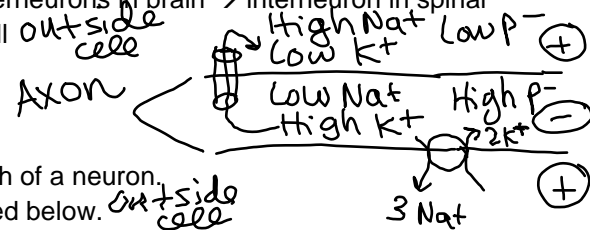


Key
 = K^+ channel (always open)
 = sodium/potassium pump

16. Most responses to the environment, however, are not reflexes. Most of the time, signals must follow the steps below.

Sensory receptor cell → sensory neuron → interneuron in spinal cord → interneurons in brain → interneuron in spinal cord → motor neuron → muscle cell

How is a signal transmitted from one end of a neuron to the other?



17. Nerve signals are a result of electrical currents that run down the length of a neuron.

18. Normally, the neuron is in a resting state. The resting state is described below.

- There is a higher concentration of potassium ions (K^+) inside the cytoplasm than outside the cell and a higher concentration of sodium ions (Na^+) outside the cell than inside the cytoplasm.
- The membrane of the neuron is not permeable to sodium ions (Na^+), but it is permeable to potassium ions (K^+).
- K^+ ions tend to flow through ion channels from the inside to the outside of the cell by diffusion, but the sodium/potassium pump maintains a state of high Na^+ outside the cell and high K^+ inside the cell by constantly pumping Na^+ out and K^+ in.

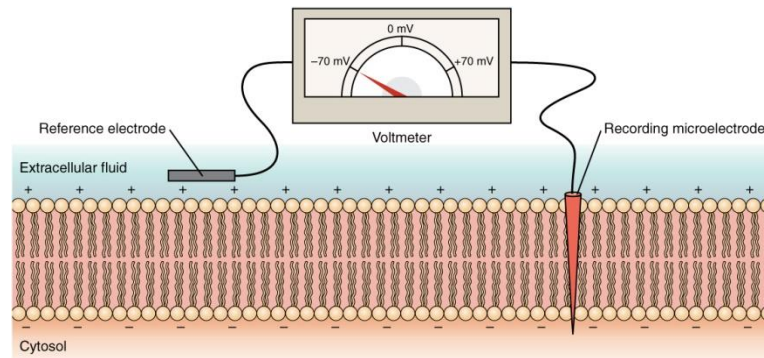
(Note: the Na^+ / K^+ pump moves 3 Na^+ out for every 2 K^+ it brings in)

P The cytoplasm has an overall negative charge compared to the outside because there are many negatively charged proteins inside the cytoplasm.

-The area outside the cell has an overall positive charge compared to the cytoplasm because of the excess Na^+ (and some K^+) ions.

-There is an electrical charge difference between the cytoplasm and outside the cell of **-70 mV (milliVolts)**. Because this is the normal charge of a nerve cell, we call -70 mV the resting potential of the cell.

19. Initially, scientists measured the resting potential of a nerve cell using a microelectrode placed inside the cell, a reference microelectrode placed outside the cell, and a voltmeter (voltage meter).



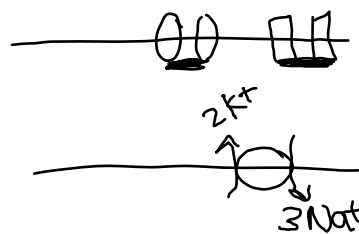
key →
 ○ = sodium/potassium pump
 □□ = voltage-gated Na⁺ channel (closed)
 □□ = voltage-gated K⁺ channel (closed)

20. A nerve cell is not always at resting potential, however. An **action potential** occurs when a neuron sends information down an axon, away from the cell body. Neuroscientists use other words, such as a "spike" or an "impulse" for the action potential. The action potential is an explosion of electrical activity that is created by a depolarizing current. This means that some **event** (a stimulus) causes the resting potential to move toward 0 mV.
21. When the depolarization reaches about **-55 mV** a neuron will fire an action potential. This is the **threshold**. If the neuron does not reach this critical threshold level, then no action potential will fire. Also, when the threshold level is reached, an action potential of a fixed sized will always fire. For any given neuron, the size (**amplitude**) of the action potential is always the same. Therefore, the neuron either does not reach the threshold or a full action potential is fired - this is the **"All or None" principle**.

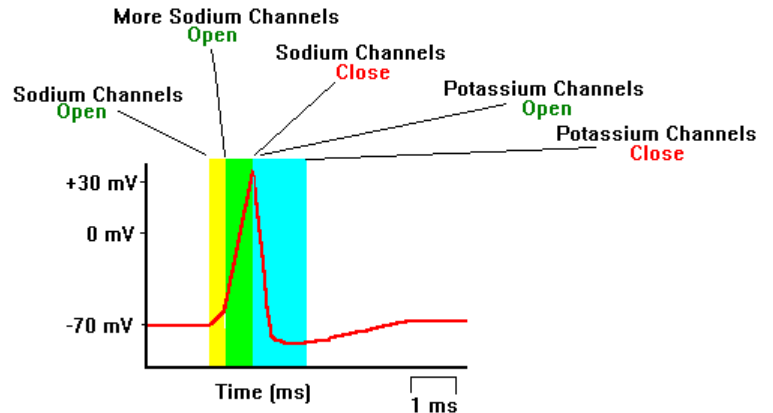
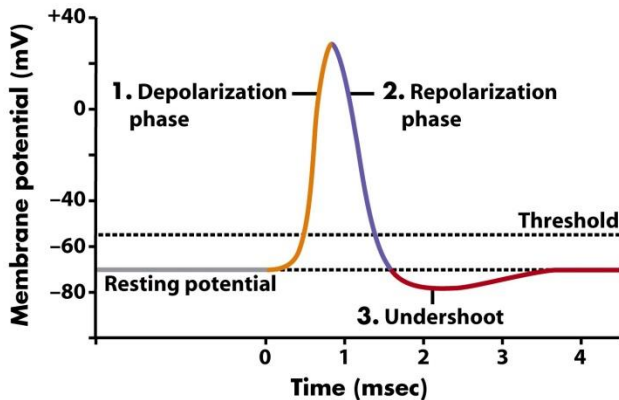
(Note: Neurons CAN increase the frequency of action potentials to transmit a more powerful signal)

22. The steps of an action potential are summarized in the chart below:

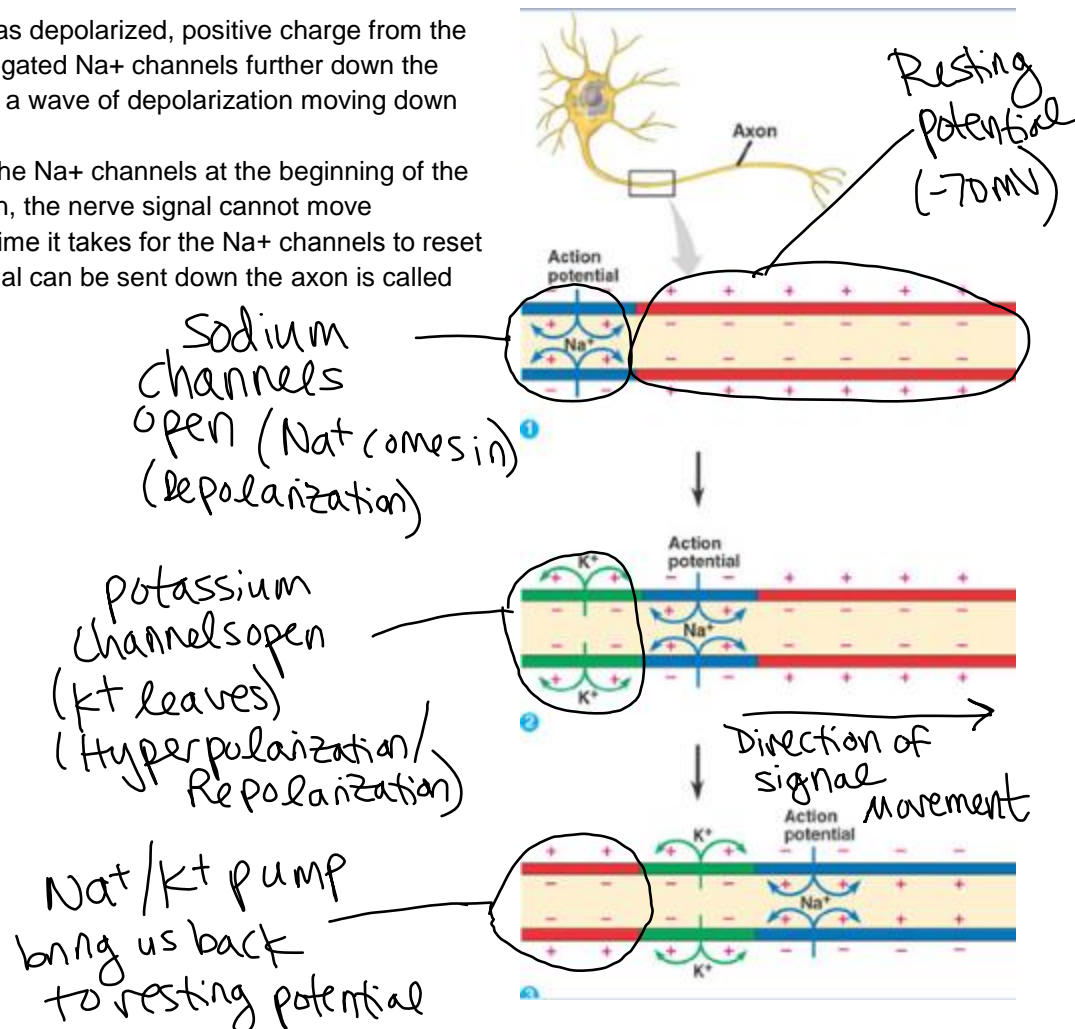
Stage Name	Description	Image (draw with Ms. Ottolini)
Threshold	Some stimulus causes the inside of the cell to depolarize to -55 mV . Once a cell reaches this voltage, it will begin an action potential.	
Depolarization	Voltage-gated Na⁺ channels open and allow Na ⁺ to diffuse into the cell, causing the membrane to depolarize to 0 mV, and gain an increasingly positive voltage. (They are called voltage-gated channels because they open in response to the stimulus / positive charge inside the cell that causes its voltage to increase to -55 mV.)	
Repolarization	Voltage gated K⁺ channels also open in response to the membrane reaching -55 mV, but they open more slowly than Na ⁺ channels. Once they open, the K ⁺ channels allow K ⁺ to diffuse out of the cell, lowering the cell's voltage back to its resting potential (-70 mV). During this stage, voltage-gated Na ⁺ channels also close, so that no more positive charge can enter the cell.	
Hyperpolarization (aka Undershoot)	Because K ⁺ channels take a long time to close, they let out some excess K ⁺ and cause the membrane potential to dip below its resting state to about -80 mV.	<p>(lots of K⁺ leaving) Same as one above!</p>

Resting Phase	Eventually the membrane returns to its resting state by the action of the sodium-potassium pump (Na^+ / K^+ pump), which pumps 3 Na^+ out and 2 K^+ in using energy from ATP.	
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23. The graphs below track the membrane voltage and opening/closing of voltage-gated ion channels throughout the phases of an action potential.

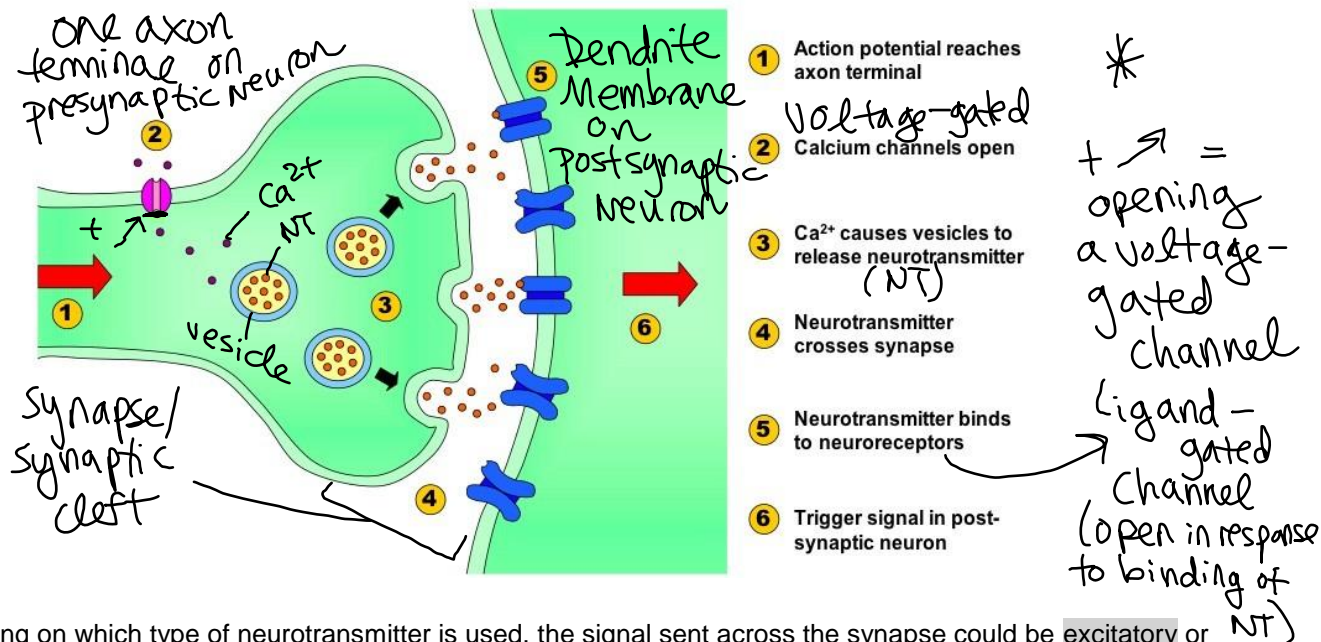


24. Once a portion of the axon has depolarized, positive charge from the influx of Na^+ causes voltage-gated Na^+ channels further down the axon to open. This results in a wave of depolarization moving down the axon.
25. Because it takes a while for the Na^+ channels at the beginning of the axon to be able to open again, the nerve signal cannot move "backwards." The period of time it takes for the Na^+ channels to reset so that another action potential can be sent down the axon is called the **refractory period**.



How is a signal sent from one neuron to another?

26. The space between two neurons is called the **synaptic cleft** or **synapse**.
27. The neuron before the synapse that sends the signal is called the **presynaptic neuron**.
28. The neuron after the synapse that receives the signal is called the **postsynaptic neuron**.
29. Below is a list of the steps involved in the passage of a signal across the synapse from a presynaptic neuron to a postsynaptic neuron.
 - The **axon terminal** of the pre-synaptic neuron receives an action potential signal. The depolarization in the axon terminal causes **voltage-gated calcium (Ca^{2+}) channels** to open and allow **calcium ions** to enter the axon terminal.
 - The influx of calcium causes synaptic **vesicles** carrying signal molecules called **neurotransmitters** to fuse with the axon terminal membrane and release neurotransmitters in the synaptic cleft.
 - Neurotransmitter molecules diffuse across the synaptic cleft and bind to **ligand-gated ion channels** on the post-synaptic (**dendrite**) membrane. (Note: *Ligand-gated ion channels open in response to the binding of a signal molecule / ligand.*)
 - The ligand-gated ion channels open and allow Na^+ to enter the cell, triggering depolarization / action potential in the post-synaptic neuron.
 - Synaptic transmission ends when the neurotransmitter diffuses out of the synaptic cleft, is reabsorbed by the pre-synaptic cell, or is degraded by enzymes in the synaptic cleft.



30. Depending on which type of neurotransmitter is used, the signal sent across the synapse could be **excitatory** or **inhibitory**. Excitatory signals cause depolarization / action potentials in the post-synaptic neuron, and inhibitory signals cause hyperpolarization (no action potentials) in the post-synaptic neuron.

What are examples of neurotransmitters that have opposing effects in the body?

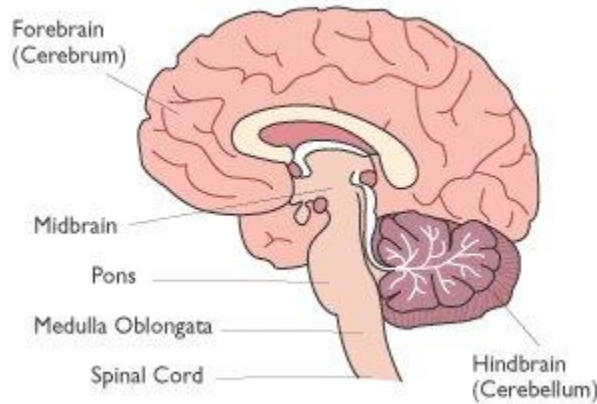
31. **Acetylcholine** and **norepinephrine** are two neurotransmitters that have opposing effects in the body (see chart below)

Effect	Norepinephrine	Acetylcholine
Which division of the nervous system does this neurotransmitter act on?	Sympathetic (active during times of stress / emergencies)	Parasympathetic (active during times of relaxation / everyday life)
How does it affect the digestive system?	Slows it down	Speeds it up
How does it affect the pupils of the eye?	Dilates them	Constricts them
How does it affect the heart rate?	Speeds it up	Slows it down
How does it affect the breathing rate?	Speeds it up	Slows it down

Do different parts of the brain control different activities?

32. Below are some examples of parts of the brain that have specific roles in the body

- The **medulla oblongata** controls heartbeat, breathing and blood pressure. It also contains the reflex centers for vomiting, coughing, sneezing, hiccuping and swallowing. It is a primitive structure responsible for basic functions.
- The **cerebellum** is responsible for fine motor movements and balance / posture.
- The **cerebrum / cerebral cortex** contains the two sides (**right and left hemispheres**) of the brain, which are responsible for consciousness. Different parts (lobes) of the cerebrum control different functions. For example, the **frontal lobe** is responsible for judgment / reasoning, the **occipital lobe** is responsible for eyesight, etc.
- The **corpus callosum** is a tissue that connects the two hemispheres of the cerebrum and allows them to share information. The corpus callosum is larger in women, and may account for women's "superior" ability to multi-task. In patients with severe seizure disorders / epilepsy, doctors occasionally cut the corpus callosum to prevent the spread of seizures from one hemisphere of the brain to the other.



Thanks to "Neuroscience for Kids" and AHSD Biology